CONTENTS

Biological Assumptions and Conceptual Study Designs for High Flow Dewatering Systems

1.0 INTRODUCTION

Successful dewatering of a high flow bypass facility at Bonneville First Powerhouse will involve the integration of hydraulic and structural engineering, fish ecology and behavior and a modicum of luck. R2 Resource Consultants previously reviewed design criteria for high flow dewatering systems in the lower Columbia River (1997a) and summarized the performance of high velocity dewatering technology employed at sites across North America (1997b). In this report, we describe assumptions integral to the use of high velocity technology and identify areas that warrant additional study should a high volume dewatering facility at Bonneville First Powerhouse involve a significant extension of new technology.

In the following section, we identify a decision process to identify between conventional (low-velocity) and high velocity screening criteria and evaluate the need for additional site-specific study. In Section 3 of this report, we discuss select dewatering design issues such as:

3.1) fast-start swimming performance of juvenile salmonids;
3.2) application of standard design criteria at the Bonneville First Powerhouse;
3.3) influence of fish fatigue on design criteria;
3.4) effect of debris load on fish passage survival and guidance efficiency; and
3.5) juvenile salmonid response to high velocity wall screens.

2.0 DECISION PROCESS

The majority of downstream fish protection devices in the Pacific Northwest present a physical barrier or physically exclude juvenile salmonids from entrainment into a turbine, water supply or irrigation intake. Incorporating knowledge of fish behavior and hydraulics, fish are provided the opportunity to enter or are "guided" into a bypass that allows fish to move past or away from the intakes. The proportion of fish actually entering the fish passage structure is often the major factor contributing to overall fish passage performance at a facility. Design of a dewatering facility at Bonneville First Powerhouse does not have to consider attracting fish into the bypass, but designing a facility to concentrate fish in a smaller volume still relies on a combination of physical, hydraulic and biological information to achieve success.

Identifying the target fish is an initial step in developing a dewatering facility. The species, size, time of migration and stock origin may all affect facility design features (Figure 1). Dewatering criteria should provide safe passage of the smallest, and presumably weakest swimming, fish. Data on species, stock and size-specific differences of swimming performance are available from laboratory studies. Some stock and species differences in swimming performance have been noted (Taylor and McPhail 1985), and natural resource agencies have adjusted criteria for sustained swimming performance based on the size of target fish. (Bates 1988).

The incidence of disease in fish entering a dewatering facility may affect swimming performance, but should not otherwise affect project design. If diseased fish are in a physiologically weakened condition, their swimming performance would be reduced and regional design criteria may provide insufficient protection. The risk of disease transmission among fish that are stressed and concentrated in low water volumes has been a concern in transport and holding facilities (Congleton *et al.* 1985). The volume of flow and short duration of exposure in the bypass facility minimizes the risk of disease transmission among downstream migrating fish.

Environmental conditions also affect the swimming performance of fish and must also be considered to ensure safe passage. A positive correlation between juvenile salmonid swimming speed and water temperature has been defined in laboratory studies (Glova and McInerney 1977; Smith and Carpenter 1987). Turbidity and total dissolved gas may affect swimming performance, but the effect is less clear. The level of suspended solids in the water column, or turbidity, can reduce the reactive distance of juvenile salmonids (Bell 1990; Gregory 1993). If successful screening depends on active movement by juvenile salmonids in response to visual stimuli, a high level of turbidity (>20 NTU, nephelometric turbidity units) would reduce screen performance.

Shiewe (1974) studied the effects of dissolved gases upon swimming performance of juvenile chinook salmon. He found that swimming ability was significantly reduced from the exposure of juvenile chinook salmon to total gas pressures above 117%. The effect of supersaturated conditions on fish is dependent on water temperature, proximity and length of exposure to total gas pressure and spatial and temporal distribution of fish in the water column. Federal and state governments have set standards for allowable levels of gas supersaturation at or below 110% in the tailraces of mainstem Columbia River dams. Monitoring of direct injury and mortality of juvenile salmonids associated with gas supersaturation is being conducted in association with a spill management plan for the Columbia River. Results of the monitoring effort may provide insights into non-lethal physiological effects of gas supersaturation including reduced swimming performance.

Assuming the target fish species, size and environmental conditions during the outmigration period are identified, a decision must be made whether to use low or high velocity technology for the design of the dewatering facility (Figure 1). Structural guidance devices such as louvers or angled bar racks and behavioral guidance devices are not accepted for use by natural resource agencies in the Pacific Northwest because they have not proven successful over a wide range of conditions. Conventional, low velocity screens have been successfully used at a variety of sites, but the size of a facility designed to screen large flow volumes becomes prohibitively expensive to construct and maintain. In cases where forebay velocities are high or where available installation area is limited, consideration of high velocity dewatering technology is warranted.

The volume of flow to be dewatered and available installation area influence the selection of low velocity or high velocity technology, but the potential fatigue of fish entering and exiting the dewatering facility should also be considered. Low velocity technology relies on a fish exerting sustained swimming effort with red, oxidative muscle fiber. High velocity technology relies on a fish exerting a fast-start swimming effort using white muscle fiber. The recovery period of each muscle group is much different and degree of fatigue may be an important factor in the survival of fish entering or exiting the dewatering facility. These and other select design issues are addressed in greater detail in the following section.

3.0 SELECT DESIGN ASSUMPTIONS

3.1 FAST-START SWIMMING PERFORMANCE OF JUVENILE SALMONIDS AT HIGH VELOCITY SCREENS

Salmonids exhibit a variety of swimming patterns over their range of swimming speed and acceleration rates. No swimming pattern works equally well in all situations and a swimming pattern that provides elevated performance for a particular function will provide poorer performance in other activities. Three primary swimming patterns have been characterized by Bell (1992) as cruising, sustained and burst or darting.

Cruising: Refers to long term movement, such as ocean migration, that can be maintained for hours. At cruising speed, fish are capable of passing water over their gills at a rate necessary to satisfy oxygen requirements.

Sustained: Refers to the maximum swimming performance of a fish maintained for several minutes. Sustained swimming is characterized by continuous cyclic movement of the body and caudal fin. These high velocity movements are powered by oxidative muscles (“red muscle”) which are slow to fatigue but require long recovery periods.

Burst or darting: Refers to swimming movement that can only be maintained for 5 to 15 seconds. During a burst movement a fish maintains cyclic tail-beat movements of small amplitude but of greater frequency than a sustained swimming pattern. The greater frequency of tail beats is powered by white muscle which fatigues rapidly, limiting the duration of “burst” exertion.

A fourth swimming pattern has been described by researchers as a **‘fast-start’** movement (Taylor and McPhail 1985, Webb 1995). During fast-start situations, fish achieve rates of acceleration higher than burst or darting speeds for 1 to 2 second duration. These fast-start situations are characterized by large body-tail motions of greater amplitude than burst movement and transient but high frequency tail beats (Webb 1995). Fast-start movements are powered by white muscle which fatigues quickly but has a short recovery time.

Some researchers believe that the switch between swimming patterns is abrupt (Behlke et al 1991), similar to the change in the gait of a horse between a trot and canter. Other researchers maintain that the switch is a gradual transition or patterns can be combined. Webb (1995) theorized that in order to reduce fatigue, a fish may use a burst-and-coast swimming pattern, alternating burst-powered swimming with an unpowered coast. Our understanding of the swimming performance of Pacific salmon is still rudimentary and as described by Webb (1995) "The lack of good data and quantitative indices for body form and function means that no definitive statement on the locomotor biology of Pacific salmon (or any other genus) can be made at this time".

When juvenile salmonids enter an Eicher or MIS facility, they must be able to maintain locomotor function and control their position in the flowline. As they sense or encounter the inclined screen, they exhibit a brief powerful swimming movement or "fast-start" response away from the screen. Design criteria for high velocity inclined screens are presently based on tests and observations of screens that have been designed following a general arrangement of proven performance. Review of design criteria for the Puntledge Eicher screens, Green Island MIS, Howard Hanson Dam MIS and Wynoochee Dam Eicher Screen reveals a consistent list of assumptions and design constraints. A better understanding of the physiological attributes of juvenile salmonid fast-start behavior may allow us to design and develop dewatering facilities that extend the boundaries of our present criteria. Tests of salmonid physiology, such as the rate of red and white muscle development in salmonid fry, the recovery rate after white muscle exertion, or confirmation of fast-start swimming speeds might lead to innovative solutions.

3.2 INFLUENCE OF FISH FATIGUE ON DESIGN CRITERIA

One of several alternatives under consideration for the proposed high flow dewatering facility at Bonneville First Powerhouse is the use of a parallel series of high velocity inclined screens. Use of multiple screens in parallel could reduce bypass flows from 20,000 cfs to 1,000 cfs. A secondary dewatering facility is being considered to further dewater the 1,000 cfs bypass flow to approximately 30 cfs. At a project design meeting held on 01 July 1997, conventional screening criteria were assumed to guide design of all secondary screening facilities. Rationale for reliance on conventional screening criteria for the secondary screen was stated as "Conventional criteria are applied in this case to be conservative since as fish become concentrated in less water, there is more potential for injury" (ENSR 1997).

Conventional screening criteria rely on the sustained swimming performance of fish to avoid impingement and injury. It is unclear whether existing screening criteria are appropriate for secondary screens and whether conventional screens hold a clear advantage over high velocity screens as a secondary facility. Tests of multiple in-line screens are infrequent and primarily limited to situations where secondary screens are used to evaluate fish survival at the primary screen. At some projects, multiple screens are required due to space constraints or other considerations.

Since 1992, the configuration of the downstream migrant bypass system at the T.W. Sullivan Plant has consisted of three major components; the forebay guidance system, the turbine bypass system (Eicher screen), and the fish evaluator system (Cramer 1997). Downstream migrating salmonids enter a 10 foot diameter penstock through trash racks. After entering the penstock, fish proceed downstream to a series of Eicher screens. Two Eicher screens, both constructed of wedgewire material are placed in a "hump-back" configuration. The first screen section is placed at a 19° angle to flow and can be rotated 33° to clean. The downstream screen section is fixed permanently in a slightly downward sloping direction. After passing the fixed screen, fish exit the penstock through a rectangular bypass conduit before passing over a control gate. From the bypass, fish fall into a large plunge pool and are diverted into a fish evaluation facility via the discharge channel. The fish evaluation system is designed to divert 36 cfs of water through a spillway chute into the tailrace by way of a bar screen, while the fish and 14 cfs of water pass down the test channel, over an inclined screen, and into a 6 inch pipe that drains into a holding box. Thus, fish finding their way into the holding box have successfully passed through five screens (including the trash racks). Salmonid juveniles have successfully passed through the T.W. Sullivan downstream migrant system incurring less than 3% mortality (Cramer 1997).

Juvenile salmonids have passed successfully through multiple screening facilities, but it is uncertain whether conventional or high velocity criteria are advantageous as secondary screens. Conventional screening criteria rely on the sustained swimming performance of fish to avoid impingement and may allow a fish to become fatigued before entering the bypass facility. Because sustained swimming patterns are powered by red muscle fiber, an extended recovery period is required before maximum red muscle exertion can be repeated. If the primary screen facility relies on the sustained swimming performance of fish, existing conventional criteria may not be appropriate for a secondary screening facility. For similar reasons, if the bypass outfall exits in an area requiring sustained swimming effort, an available reserve of red muscle power may be important to survival.

If a primary screening facility relies on fast-start movements to avoid impingement, such as the MIS or Eicher screens, arguments can be made for and against designing secondary screening criteria based on either sustained or fast-start movements to avoid impingement. Salmonid fry passing across the face of a high velocity screen typically require only one or two fast-start movements before entering the bypass. The white muscle reserves are not completely depleted and recovery is rapid. If the secondary dewatering screen is designed using fast-start criteria, salmonid fry may pass successfully through the second screen and still have red muscle energy reserves available for sustained movement after exiting the bypass outfall. If successive fast-start movements are required after exiting the outfall, such as darting to avoid predation, it may be advantageous to have white muscle power in reserve.

As salmonid fry become fatigued, they may switch swimming patterns and use a burst and coast gait to conserve rapidly depleting reserves (Carpenter 1987). This burst and coast swimming pattern may be powered by white and red muscle fibers and may completely exhaust the energy reserves of the fish. When completely fatigued, salmonid fry are particularly susceptible to injury, disease or predation. Preventing the complete exhaustion of fish passing through a dewatering facility is the obvious goal; however, the process which may best achieve that goal deserves further attention. Biological tests could be designed to evaluate multiple in-line conventional and high velocity screens and determine whether multiple screens lead to exhaustion and injury. Identifying whether salmonid fry benefit from prior exposure and 'learn' to pass successive dewatering facilities may also merit further attention.

3.3 APPLICATION OF STANDARD DESIGN CRITERIA AT THE BONNEVILLE FIRST POWERHOUSE

Once a decision is reached between low velocity and high velocity dewatering technology, screen criteria based on sustained or fast-start fish swimming performance must be identified. Much of the data on sustained swimming performance of salmonids has been developed from laboratory studies. Controlled, repeatable laboratory tests allow a range of velocities to be evaluated over a range of water temperatures, but available tests of sustained swimming performance often did not closely replicate in-situ conditions. We found surprisingly few controlled, repeatable field studies testing sustained swimming performance over a range of water velocities. In contrast, the majority of data on fast-start swimming performance has been developed from field tests using proto-type and full-scale screens. Little laboratory data is available on juvenile salmonid fast-start swimming performance.

Design criteria for fish protection facilities in the Columbia River basin are based on tests and observations of fish and facilities throughout the United States and Canada. Design criteria for screening and dewatering facilities that rely on the sustained swimming performance of fish to avoid impingement are primarily developed from laboratory tests of hatchery reared salmonids from western Washington and Alaska (Smith and Carpenter 1986). Design criteria that rely on salmonid fast-start swimming ability to avoid impingement are developed from hydraulic tests and in-situ tests conducted at projects in operation in Oregon, Washington and New York states and British Columbia. Potential differences between stocks tested at existing projects and juvenile salmonids passing Bonneville First Powerhouse could be dramatic and could affect the success and cost of proposed dewatering facilities.

Differences in swimming speeds have been observed in both wild and laboratory reared juvenile salmonids and in different stocks of the same species (Taylor and McPhail 1985; Webb 1995). Differences in burst swimming abilities are influenced by body robustness (Taylor and McPhail 1985), and Besner and Smith (1983) observed that coho salmon juveniles exhibited significantly higher swimming performance after exposed to periods of exercise. Because a fish utilizes white muscle fiber to power fast-start swimming, maturation will affect the volume and proportion of white to red muscle fibers and maximum swimming speeds. The amount of muscle fiber and musculature development varies between species, but in rainbow trout fry, muscle fiber developed rapidly during the first several weeks after hatching (Carpenter 1987). The majority of salmonid outmigrants passing the Bonneville First Powerhouse have already passed at least one mainstem project and may be larger and more robust than salmonid fry used in the various Eicher and MIS evaluations.

During tests of salmonid fry at the Elwha Eicher Screen Project, an average of 91.6% of coho fry averaging 44 mm in length survived passage through the facility, compared to 97.1% of steelhead fry, averaging 52 mm in length. Chinook pre-smolts, averaging 73 mm in length, were also tested and 99.9% of those fish survived (Winchell et al. 1993). Those tests are supported by other studies that have theorized that the absolute swimming speed of salmonids is positively correlated to length (Hyde et al. 1968; Brett and Glass 1973; Webb 1995). Nearly all of the subyearling chinook passing the Bonneville First Powerhouse are larger than the coho fry used in evaluations of the Elwha Eicher Screen, and the majority of Columbia River subyearling chinook are larger than the 73 mm chinook pre-smolts used in the Elwha tests.

Confidence in the appropriate level of design performance for the Bonneville First Powerhouse can be improved with studies using juvenile salmonids that are expected to pass the project. Subyearling chinook could be captured in the reservoir upstream of the Bonneville Dam using trap nets to minimize stress and injury. Fish captured in the reservoir could be used to evaluate the performance of alternate design features of the high flow dewatering facility. Information gained through tests of the swimming performance of juvenile salmonid stocks passing the Bonneville First Powerhouse could improve the success of the proposed project. Tests conducted using Columbia River subyearling chinook could also potentially reduce costs by confirming the success of less costly design configurations.

3.4 EFFECT OF DEBRIS LOAD ON FISH PASSAGE SURVIVAL AND GUIDANCE EFFICIENCY

Eicher and MIS technology rely on a backwash cycle to flush debris from the screen. Build up of debris on the screen face will increase pressure differential across the screen and can reduce fish passage efficiency and increase the incidence of impingement, particularly for salmonid fry. Increased impingement of fish with debris accumulation on the face of the screen has been observed at the Elwha Screen (Winchell and Taft 1992) and at laboratory and prototype tests of

MIS screens (Taft et al. 1994; Shiers and Taft 1996). During a backwashing cycle, the screen is rotated to allow velocities in the conduit to flow through the screen from back to front, removing debris which may have lodged on the screen face. During the backwash cycle, fish pass the screen without being guided into the bypass. Fish passing the screen are also exposed screen support members and may be killed or injured if they strike part of the frame.

Two Eicher screens are operated by B. C. Hydro at the Puntledge River Project near Courtenay, British Columbia. These screens are cleaned by backwashing every four hours by automatic timer on independent cycles (Bengeyfield 1994). One complete backwash cleaning cycle can be conducted in approximately three minutes; thus, the Eicher screen is not in normal operating position 18 minutes a day or approximately 1.25% of the time. This frequency of cleaning has been continued for over five years of operation (Smith 1997). Even with periodic cleaning, the Puntledge Eicher screens tend to collect small supple twigs and grasses which partially penetrate the screen face and are not easily dislodged during backwashing. A large percentage of chum salmon fry released in 1994 were observed impinging on the screen face, sliding and encountering debris lodged in the screen face. Latent mortality of fish recaptured during the tests was less than 3%, which was remarkable considering the numerous observations of fish striking debris on the screen face (Bengeyfield 1995). One unexpected maintenance difficulty at the Puntledge site was the colonization of black fly larvae (Simulidae spp.) on the screen frame and backside of the screen face. The larvae restricted screen porosity and required pressure washing of the screen prior to the salmonid smolt outmigration season.

At the T. W. Sullivan Plant, located at Willamette Falls, Oregon, Portland General Electric has operated an Eicher screen in its present configuration since 1992. The Eicher screen was constructed in a 10 foot diameter penstock and screens a flow of approximately 450 cfs. Pressure differential (head loss) across Eicher screen is monitored continuously. When head loss reaches 18-20 inches, the screen is rotated into a backflush or cleaning position. During the cleaning cycle, flow is reduces to five percent to reduce the number of fish entering the penstock. The total cleaning cycle, including reducing the flow through the penstock, takes approximately 19 minutes to complete. During extreme fall freshets, the screen must be cleaned up to once every hour. From spring through early fall, the screen will operate for extended periods without cleaning.

The quantity and type of debris suspended in the Columbia River varies by season and flow level. Following large flood events, shoreline woody debris, leaves and other detritus are transported in the water column and clog screens and trash racks. Management of debris may be possible during high flow events with increased attention to trash racks and debris booms. Summer low flow events however, also present a debris problem which may be more difficult to manage. During low flow periods, colonies of filamentous algae become suspended in the water column and may clog high velocity screens. The algae feels slimy when handled, and frequent backflushing may be required to maintain even pressure differences across the screen. At PacifiCorp's Umpqua project, a drum screen facility built in the 1950's was abandoned soon after installation because large blooms of filamentous algae clogged the screen mesh. Small prototype tests of a high velocity screen at the Bonneville site would identify maintenance requirements and expected effectiveness and frequency of backwash cleaning cycles.

3.5 JUVENILE SALMONID RESPONSE TO HIGH VELOCITY WALL SCREENS

Potential design configurations of the high flow dewatering facility at the Bonneville First Powerhouse involves use of high velocity inclined and wall screens. All Eicher and Modular Inclined Screens (MIS) studies to date have been configured about a horizontal axis from front to rear at an angle of 15° to 22°. One of the options considered for design of the Bonneville de-watering facility involved use of a high velocity wall screen which pivots on a vertical axis from front to rear. The response of juvenile salmonids to high velocity wall screens may be similar to a response to high velocity inclined screens, but there are insufficient data available to confirm the assumption.

As juvenile salmonids encounter the boundary layer turbulence or screen face of an Eicher screen, they exert a fast-start movement away from the screen. The movement has both a forward and vertical component. The velocity of the water parallel to the screen face (sweeping velocity) guides the fish in the direction of the bypass entrance. The vertical component of the fast-start response may be a movement of the fish perpendicular to the screen face, an effect of the sweeping velocity, or may be an instinctive response to move upwards in the water column.

If fish encountering an Eicher screen exert a vertical movement as an instinctive response, the location of the bypass entrance at a wall screen may affect passage duration and overall fish passage survival. The duration of exposure to the screen face may be shorter in an Eicher screen with a bypass located in the upper portion of the conduit than at a high velocity wall screen with a bypass located on the side of a conduit. Juvenile salmonids exhibit increased buoyancy with advancing stage of smoltification. Increased buoyancy and surface orientation is believed to assist a smolt travel downstream by taking advantage of waves and turbulence to minimize energy expenditures. The general surface orientation of outmigrating juveniles in rivers and reservoirs has been amply demonstrated. However, fish have also been observed orienting to the upper portion of the column within turbine intakes, often passing along the ceiling (Cada et al. 1997). If a fast-start movement includes a vertical component, location and design of the bypass at high velocity wall screens may be critical.

It would be relatively simple to design and conduct a study to determine the response of outmigrants to inclined and wall screens. Videotaping the response of juvenile salmonids encountering a variety of high velocity screen angles and configurations might increase confidence in the use of high velocity wall screens where site constraints hinder use of inclined screens.

Unless there were strong engineering considerations, a conservative approach to design criteria would rely on the known design parameters of high velocity inclined screens.

4.0 SUMMARY

Design criteria to guide development of the Bonneville First Powerhouse high flow dewatering facility will be developed based on observation, laboratory and field tests conducted at other projects, and past operating experiences. Review of the success and failures of specific design parameters at existing facilities provides confidence in the potential success of the Bonneville Project, but even well-established fish passage technologies rely on assumptions at a given site application. Testing of design assumptions increases the likelihood of a successful project and provides the opportunity to reduce design constraints which may lower construction and maintenance costs while maintaining or increasing fish passage survival.

5.0 REFERENCES CITED

Bates, K. 1988. Screen criteria for juvenile salmon. Washington Department of Fisheries, Olympia, Washington. pp. 14.

Bell, M.C. 1992. Fisheries handbook of engineering requirements and biological criteria, U.S. Army Corps of Engineers, Fish Passage Development and Evaluation Program.

Behlke, C.E., D.L. Kane, R.F.McLean, and M.D. Travis. 1991. Fundamentals of culvert design for passage of weak-swimming fish. Alaska Department of Transportation and Public Facilities, Report no. FHWA-AK-RD-90-10. pp. 159.

Bengeyfield, W. 1994. Evaluation of the Eicher screen at Puntledge Diversion Dam in 1993. Global Fisheries Consultants Ltd. Prepared for B.C. Hydro, Environmental Resources, Burnaby, British Columbia. pp. 36.

Bengeyfield, W. 1995. Evaluation of the Eicher screen at Puntledge Diversion Dam, Year 2 (1994). Global Fisheries Consultants Ltd. Prepared for B.C. Hydro, Environmental Resources, Burnaby, British Columbia. pp. 39.

Besner, M. and L.S. Smith. 1983. Modification of swimming mode and stamina in two stocks of coho salmon (*Oncorhynchus kisutch*) by differing levels of long-term continuous exercise. Can. J. Fish. Aquat. Sci. 40:933-939.

Brett, J.R. and N.R. Glass. 1973. Metabolic rates and critical swimming speeds of sockeye salmon (*Oncorhynchus nerka*) in relation to size and temperature. Journal of the Fisheries Research Board of Canada. 30:379-387.

Cada, G.C., C.C Coutant, and R.R. Whitney. 1997. Development of biological criteria for the design of advanced hydropower turbines. U.S. Department of Energy, Idaho Operations Office, DOE/ID-10578. pp. 85.

Carpenter, L.T. 1987. A comparative study of short-term swimming performance in fry of five salmonid species at different temperatures. M.S. Thesis. University of Washington, Seattle, Washington. pp. 223.

Congleton, J.A., T.C. Bjornn, B.H. Burton, B.D. Watson, J.I. Irving, and R.R. Ringe. Effects of handling and crowding on the stress response and viability of chinook salmon parr and smolts. Bonneville Power Administration, Portland, Oregon, Project 82-5, Contract DE-AC79-83BP11196. 151 pp.

Cramer, D. 1997. Evaluation of a louver guidance system and Eicher screen for fish protection at the T.W. Sullivan plant in Oregon. Presented at the Fish Passage Workshop. Milwaukee, Wisconsin. pp. 14.

ENSR. 1997. [Record of June 30 and July 1, 1997 meeting] Bonneville First Powerhouse Surface Collector High flow Dewatering Facility and Outfall Location Study. USACE Contract No. DACW57-97-D-007, Task Order No. 0001. ENSR Consulting and Engineering, Redmond, Washington. pp. 13.

Glova, G.J., and J.E. McInerney. 1977. Critical swimming speeds of coho salmon (*Oncorhynchus kisutch*) fry to smolt stages in relation to salinity and temperature. Canadian Journal of Fisheries and Aquatic Sciences 34:151-154.

Gregory, R.S. 1993. Effect of turbidity on the predator avoidance behavior of juvenile chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 50:241-246.

Hyde, H.C., R.W. Smith, N.D. Geddes, J.R. Munn. 1968. Delta Fish Protective Facility Functional Design. California Department of Water Resources. March, 1968. pp. 76.

R2 Resource Consultants, Inc. 1997a. Review of Screening Criteria and technology for high flow fish passage systems in the Columbia River. Report to US Army Corps of Engineers, Portland District, Contract No. DACW57-96-D-0007. Portland, Oregon. pp 65.

R2 Resource Consultants, Inc. 1997b. Summary of available literature regarding high flow fish passage systems. Report to US Army Corps of Engineers, Portland District, Contract No. DACW57-96-D-0007. Portland, Oregon. 17 pp.

Shiers, P.F., and E.P. Taft. 1996. Evaluation of the modular inclined screen (MIS) at the Green Island hydroelectric project: 1995 test results. Report Number TR-1064983672-01. Prepared by Stone and Webster Environmental and Alden Research Laboratories Inc. for the Electric Power Research Institute. Palo Alto, California. 116 pp.

Shiewe, M.H. 1974. Influence of dissolved atmospheric gas on swimming performance of juvenile chinook salmon. Transactions of the American Fisheries Society 103:717-721.

Smith, H. 1997. Operating history of the Puntledge River Eicher screen facility. Presented at the Fish Passage Workshop. Milwaukee, Wisconsin. 6 pp.

Smith,L.S. and L.T. Carpenter. 1987. Salmonid fry swimming stamina data for diversion screen criteria. Fisheries Research Institute, University of Washington, Seattle, WA; prepared for Washington Department of Fisheries and Wildlife, Olympia, Washington. pp. 101.

Taft, E.P., F.C. Winchell, S.V. Amaral, and T.C. Cook. 1994. Fish protection/passage technologies evaluated by EPRI and guidelines for their application. Prepared by Stone & Webster Engineering Corporation. Electric Power Research Institute, Palo Alto, CA. EPRI TR-10420. 203 pp.

Taylor, E.B. and J.D. McPhail. 1985. Variation in burst and prolonged swimming performance among British Columbia populations of coho salmon, *Oncorhynchus kisutch*. Can. J. Fish. Aquat. Sci. 42:2029-2033.

Webb, P.W. 1995. Locomotion. *In*: Physiological ecology of Pacific salmon, edited by Groot, C., L. Margolis, and W.C. Clarke. University of British Columbia Press, Vancouver, British Columbia.

Winchell, F.C., and E.P. Taft. 1992. Evaluation of the Eicher Screen at Elwha Dam: 1990 and 1991 test results. Prepared by Electric Power Research Institute, Palo Alto, CA. EPRI TR-101704, Project 2694-01. 239 pp.

Winchell, F., N. Taft, T. Cook, and C. Sullivan. 1993. Research update on the Eicher screen at

Elwha Dam. Pages 344-353 *in* W. D. H. editor. Waterpower '93. Nashville, Tennessee.